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FOR

Enhanced Flow Channel for Component Cooling in Computer Systems

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Enhanced Flow Channel for Component Cooling in Computer Systems

FIELD OF THE INVENTION

[0001] The present invention pertains to the field of computer system design. More particularly, the present invention relates to a thermal management technology for notebook computers.

BACKGROUND OF THE INVENTION

[0002] A computer system typically comprises a plurality of electronic components. Such components may include a central processing unit (CPU), a chipset, and a memory. During operation, the components dissipate heat. In addition, voltage stepping inside the computing system also generates heat. If the CPU, or any other electronic component, becomes overheated, performance may suffer and the component's life may be depreciated.

[0003] A thermal management system is typically used to remove heat from a computer system. An example of a thermal management system is a two-phase cooling loop. A two-phase cooling loop also uses a pump to circulate a working fluid to cool a component of a system. A two-phase loop typically uses a working fluid such as water. An evaporator or cold plate picks up heat from the component. Figure 1 depicts a prior art cross-sectional view of an evaporator 120 that picks up heat from a component 110. The evaporator has uniformly spaced micro-channels that provide a path for the heat to travel from the component 110. The heat causes the working fluid to change phase from a

liquid to a mixture of liquid and vapor or pure vapor. The working fluid is output from the evaporator to a heat exchanger, condenser, or heat sink. The heat exchanger is typically coupled to a fan that rejects the heat from the working fluid to the ambient air. The vapor condenses in the heat exchanger, converting the working fluid back to liquid. A pump is used to drive the working fluid to the evaporator to complete the loop.

[0004] Another example of a thermal management system is a refrigeration loop. Similar to a two-phase cooling loop, a refrigeration loop may comprise a liquid phase and a vapor phase. A refrigeration loop typically uses a working fluid such as Freon to cool a component of a system. An evaporator picks up heat from the component. The heat causes the working fluid to change phase from a liquid to a mixture of liquid and vapor or pure vapor. A pump, working as a compressor, then transports the working fluid to a heat exchanger. The compressor compresses or increases the pressure of the gas, which results in increase in temperature of the fluid. The heat exchanger is typically coupled to a fan that rejects the heat from the working fluid to the ambient air, turning the working fluid back into a liquid. The liquid, however, is still at a high pressure. An expansion valve reduces the pressure of the working fluid and returns the working fluid to the evaporator to complete the loop. The fundamental difference between the refrigeration loop and the two-phase loop is that the heat exchanger in the refrigeration loop typically has a higher temperature than the heat exchanger in the two-phase loop.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a prior art evaporator;

FIG. 2A is a top view of an embodiment of an evaporator comprising micro-channels having different channel widths;

FIG. 2B is a cross-sectional view of an embodiment of an evaporator comprising micro-channels having different channel widths;

FIG. 3 is an embodiment of an evaporator that directs the path of the working fluid to gradually warm the working fluid;

FIG. 4A is a side view of an embodiment of an evaporator that gradually warms the working fluid to improve the heat flow to the working fluid;

FIG. 4B is the cross-sectional view of an embodiment of an evaporator that gradually warms the working fluid to improve the heat flow to the working fluid;

FIG. 5 is an embodiment of an evaporator micro-channel having an aperture;

FIG. 6 is an embodiment of an evaporator micro-channel having an indentation;

FIG. 7 is an embodiment of an evaporator micro-channel having a sintered copper powder layer;

FIG. 8 is an embodiment of an evaporator micro-channel having a sintered copper powder wall;

FIG. 9 is an embodiment of a two-phase cooling system loop comprising an evaporator having an enhanced flow channel design;

FIG. 10 is an embodiment of a refrigeration cooling system loop comprising an evaporator having an enhanced flow channel design; and

FIG. 11 is an embodiment of a silicon die comprising micro-channels having different channel widths.

DETAILED DESCRIPTION

[0005] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

[0006] The component cooled by a thermal management system may not have uniform heat distribution across its surface. For example, an evaporator may pick up heat from a CPU die that comprises a core area and a cache area. The core area may consume more power and generate more heat than the cache area.

[0007] The higher the heat transfer coefficient, the better heat is dissipated from the component by the thermal management system. Convection heat transfer is defined by the formula:

$$Q = h * A * (T1-T2),$$

where h is the heat transfer coefficient, A is the heat transfer surface area, T1 is the temperature of the evaporator surface, and T2 is the temperature of the working fluid. Enhanced heat transfer surface structures may increase the pressure drop to increase the heat transfer coefficient.

[0008] Heat is transferred from the component to the working fluid by the evaporator. Micro-channels in the evaporator provide a fluid or an air flow path

from the component. As discussed above, heat from the component generates vapors in the working fluid. A component, such as a CPU die, that has a temperature gradient across its surface will generate the most vapors over the area in which the component is most hot. The area having a greater amount of vapors may push the working fluid towards other areas. Thus, a component having temperature gradients across its surface area may result in degradation of heat transfer to the working fluid.

[0009] For an embodiment of the invention, an evaporator or cold plate comprising micro-channels having different channel widths is used with a component having a non-uniform heat distribution to maximize the pressure drop across the evaporator. The evaporator and its micro-channels may comprise copper or silicon. The channel widths may range from 50 microns to 1000 microns. An evaporator is depicted in Figures 2A and 2B. However, the same design may be used with a cold plate. Figure 2A is a top view of the evaporator 220. Figure 2B is a cross-sectional view of the evaporator 220. The evaporator 220 is thermally coupled to component 210. Component 210 comprises a first area 212 and a second area 214. The first area 212 and second area 214 may generate differing amounts of heat.

[0010] The channel widths of the evaporator 220 may be such that the channel widths are largest over the area of the component 210 that dissipates the most heat. Therefore, to provide evaporator 220 with better heat distribution, the channel widths over the second area 214 may be greater than the channel

widths over the first area 212 if the second area 214 generates more heat than the first area 212 to improve the heat flow between channels. On the other hand, the channel widths over the first area 212 may be greater than the channel widths over the second area 214 if the first area 212 generates more heat than the second area 214. Matching the channel width to the heat generated under the channels helps in reducing flow maldistribution in the channels.

[0011] To minimize the thermal interface resistance between component 210 and evaporator 220, a thermal interface material 230 may be coupled between component 210 and evaporator 220. The thermal interface material 230 may comprise thermal grease, polymer, or metallic alloys.

[0012] For another embodiment of the invention, the micro-channels are built into the die itself rather than on a discrete evaporator or cold plate as depicted in Figure 2B. Figure 11 depicts channels that are integrated into the backside of a die. The die may comprise areas 1112 and 1114. The area 1114 may have a higher temperature than the area 1112. In order to reduce flow maldistribution in the channels, the channels of the die are positioned such that the channel widths over area 1114 are greater than the channel widths over area 1112.

[0013] For the embodiment of the invention depicted in Figure 2A, the working fluid enters through the left side of the evaporator 220 and exits through the right side of the evaporator 220. The working fluid may comprise water, super critical carbon dioxide, Freon, ammonia, methanol, acetone, ethanol, or

heptane. For another embodiment of the invention, the evaporator or cold plate of Figure 3 directs the path of the working fluid to gradually warm the working fluid by thermally coupling the working fluid to the hottest portion of a component last.

[0014] Figure 3 depicts a top view of evaporator 320. Evaporator 320 is thermally coupled to a heat generating component. A heat generating component may be disposed adjacent to the evaporator 320. The component comprises a first area 312 and a second area 314. The second area 314 may generate more heat than the first area 312. As a result, the evaporator 320 directs the working fluid first to area 312 prior to reaching the area 314. This working fluid flow pattern allows a gradual increase in working fluid temperature, which helps to remove subcooling and to enable two-phase cooling over area 314. For another embodiment of this invention, the flow pattern as described in Figure 3 may be integrated into the backside of a silicon die.

[0015] Moreover, the channel widths of the evaporator 320 over component area 314 may be larger than the channel widths over component 312. As discussed above, the larger channel widths over the hotter component areas help to improve the heat flow to the working fluid.

[0016] Figures 4A and 4B depict yet another embodiment of the invention. Similar to evaporator 320, evaporator 420 gradually warms the working fluid to improve the heat flow to the working fluid. Figure 4A shows the side view of evaporator 420. Figure 4B shows the front view of evaporator 420. Evaporator

420 comprises a divider 425 that separates the evaporator 420 into a top portion and a bottom portion. A thermal interface material 430 is coupled to the evaporator 420. A component 410 that generates heat is coupled to the thermal interface material 430. The thermal interface material 430 may be used to reduce the thermal interface resistance between the component 410 and the evaporator 420.

[0017] Liquid may enter the evaporator 420 through the top portion. Because the bottom portion is physically closer to the component 410, the working fluid in the bottom portion may have a higher temperature than the working fluid in the top portion. Since heat rises, heat travels from the bottom portion to the top portion. Hence, the top portion pre-heats the fluid and eliminates or reduces subcooling such that the fluid reaches its saturation temperature as it reaches the die. This helps to ensure boiling heat transfer throughout the length of the die.

[0018] The divider 425 may comprise copper or silicon. The conductive properties of divider 425 help the top portion of the evaporator 420 capture heat from the bottom portion. As a result, the working fluid is gradually heated as it flows from the top portion to the bottom portion.

[0019] For yet another embodiment of the invention, the channel widths of the evaporator 420 may vary. For example, if component 410 comprises thermal gradients across its surface area, the channel widths over the hotter areas may be larger to improve heat flow to the working fluid.

[0020] To further increase heat transfer, the micro-channels of the embodiments of the evaporators or cold plates described above may comprise apertures. Figure 5 depicts an example of such a micro-channel 500. The micro-channel 500 has an aperture 540. A vapor formation chamber 550 and a fluid passageway 560 are coupled to the aperture 540. The fluid passageway 560 is coupled to inlet and outlet plenums that transport working fluid.

[0021] A component 510 is coupled to the micro-channel 500. Heat from the component 510 causes vapors to generate in the vapor formation chamber 550. The vapors form bubbles in the fluid passageway 560. The aperture 540 provides a nucleation site in the evaporator. A nucleation site provides an area in the evaporator for vapors to form.

[0022] The evaporator or cold plate may comprise a plurality of micro-channels. Each of the micro-channels may comprise apertures. The apertures provide nucleation sites in the evaporator. Vapor bubbles are typically randomly generated within a fluid passageway. The apertures control where the vapors are introduced within the micro-channels. The apertures allow for an even distribution of vapor bubbles throughout the evaporator and increase nucleation site density in micro-channels. As a result, the boiling heat transfer is increased.

[0023] For yet another embodiment of the invention, the micro-channels of an evaporator or a cold plate may comprise indentations instead of apertures to further improve heat transfer. Figure 6 depicts a micro-channel 600 comprising an indentation 640 on the floor surface of the micro-channel 600. The

indentation 640 is coupled to a fluid passageway 660. Heat generated by the component 610 is transferred to the working fluid of the evaporator. Vapor bubbles form in the working fluid as a result of the heat. The indentation 640 provides a nucleation site for vapor bubbles to form.

[0024] The evaporator may comprise a plurality of micro-channels. Each of the micro-channels may comprise indentations. The indentations may be positioned in a pattern in the micro-channels. The indentations may increase nucleation site density in micro-channels. As a result, the boiling heat transfer may be increased.

[0025] For yet another embodiment of the invention, the micro-channels of an evaporator or cold plate may comprise a horizontal sintered copper powder layer to further improve heat transfer. Figure 7 depicts a micro-channel 700 comprising a sintered copper powder layer 740. The sintered copper powder layer 740 is coupled to a fluid passageway 760. The fluid passageway 760 may be coupled to inlet or outlet plenums that transport working fluid. The micro-channel 700 is coupled to a component 710.

[0026] The evaporator may comprise a plurality of micro-channels. Each of the micro-channels may comprise a sintered copper powder layer. The sintered copper powder layer may provide nucleation sites for the evaporator. As heat is transferred to the evaporator, vapors are formed in the working fluid. The sintered copper powder layer increase nucleation site density in the plurality of micro-channels, improving boiling heat transfer.

[0027] For yet another embodiment of the invention, the micro-channels may comprise vertical sintered copper powder walls to further improve heat transfer. Figure 8 depicts a micro-channel 800 having a sintered copper powder wall 740. The sintered copper powder wall 740 is coupled to a fluid passageway 760. The micro-channel is coupled to a component 710.

[0028] The sintered copper powder wall 740 provides nucleation sites for vapor bubbles created by heat transferred from the component 710. By introducing sintered copper powder walls throughout the evaporator, the nucleation sites provide equal pressurization across the evaporator and improved nucleation site density. As a result, boiling heat transfer is increased.

[0029] Figure 9 is an embodiment of a two-phase cooling loop comprising an evaporator 220 that has an enhanced flow channel design of micro-channels. Evaporator 220 is coupled to heat exchanger 930. Heat exchanger 930 is coupled to fan 935 and pump 920. Pump 920 is coupled to evaporator 220.

[0030] The evaporator 220 transfers heat from a heat generating component to a working fluid. The component may have a first area and a second area. The first area may generate more heat than the second area. For example, the component may be a CPU comprising a core area and a cache area. The core area may generate more heat than the cache area. The evaporator 220 comprises micro-channels having different channel widths. Larger channel widths are used over the core area in order to minimize the pressure drop across the evaporator. The heat from the component causes the

working fluid to change from a liquid phase to a liquid and a vapor phase. The working fluid is cooled in the heat exchanger 930 by fan 935. The pump 920 returns the working fluid to evaporator 220 to complete the loop.

[0031] For another embodiment of the invention, the evaporator 320 may be used instead of the evaporator 220 in the two-phase cooling loop of Figure 9. For yet another embodiment of the invention, the evaporator 420 may be used instead of the evaporator 220 in the two-phase cooling loop of Figure 9.

[0032] Figure 10 depicts a refrigeration loop comprising an evaporator 220 that has an enhanced flow channel design of micro-channels. Evaporator 220 is coupled to pump 1020. Pump 1020 is coupled to heat exchanger 1030. Heat exchanger 1030 is coupled to fan 1035 and expansion valve 1040. Expansion valve 1040 is coupled to evaporator 220.

[0033] The evaporator 220 transfers heat from a heat generating component to a working fluid. The component may be a CPU comprising a core area and a cache area. The core area may generate more heat than the cache area. The evaporator 220 comprises micro-channels having different channel widths. Larger channel widths are used over the core area in order to maximize the pressure drop across the evaporator. The heat from the component causes the working fluid to change from a liquid phase to a liquid and a vapor phase.

[0034] The pump 1020 transfers the working fluid to heat exchanger 1030. The heat exchanger 1030 may cool the working fluid using fan 1035. Expansion

valve 1040 reduces the pressure of the working fluid before the working fluid returns to the evaporator 220.

[0035] For another embodiment of the invention, the evaporator 220 of Figure 10 may be replaced by evaporator 320 or evaporator 420. Evaporator 320 and evaporator 420 were described above in Figure 3 and Figure 4 respectively.

[0036] For yet another embodiment of the invention, evaporators 220, 320, or 420 may be used in a single-phase loop. For example, evaporator 220 may use a liquid to absorb and remove heat from a component of a computer system. The liquid may then be circulated to an area of the system where heat is passively purged through natural convection.

[0037] In the foregoing specification the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modification and changes may be made thereto without departure from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense.